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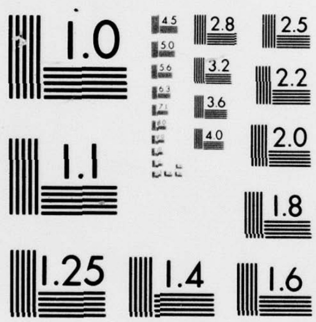

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(6) HIGH-FREQUENCY HEARING LOSS INCURRED BY EXPOSURE TO LOW-FREQUENCY NOISE, (U)

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The current damage-risk criteria (10) which define the limitations for exposure to continuous noise are specified in terms of the A-weighted levels of noise rather than the unweighted, absolute sound pressure levels of noise. A-weighted levels are derived via an electrical network found in sound measurement equipment. The effect of A-weighting is the de-emphasis or the measurement reduction of the levels of the low-frequency components of a noise. For example, absolute sound pressure levels or octave-band levels appear systemically lower by as much as 70 dB at 10 Hz, 26 dB at 63 Hz, and .8 dB at 800 Hz when measured through an A-weighting network (1). By specifying damage-risk criteria in terms of A-weighted levels, the implicit assumption is that high-intensity, low-frequency sounds are not as harmful to hearing as are high-intensity, high-frequency sounds.

This is of particular concern to the Army because of the large number of vehicles within the Army inventory which generate low-frequency noise at very intense levels. For example, analysis of the running noise generated by the Infantry Fighting Vehicle (IFV) or Cavalry Fighting Vehicle (CFV; formerly designated as the Mechanized Infantry Combat Vehicle, MICV) indicate the presence of high-intensity, low-frequency noise. In general, the greatest amount of acoustic energy occurs below 250 Hz with many low-frequency components exceeding a sound pressure level of 100 dB. The unweighted intensity levels found at 63 Hz are frequently in excess of 120 dB sound pressure level (9).

Another factor which must be considered is that most hearing protectors characteristically provide poor attenuation at the low frequencies (3). Consequently, it is more difficult to protect hearing from high-intensity, low-frequency noise than from high-intensity, high-frequency noise.

Therefore, given the factors that (1) many Army vehicles generate high-intensity, low-frequency noise, (2) most hearing protectors are relatively ineffective for low-frequency noise, and (3) the current damage-risk criteria are based on a measuring scale that de-emphasizes the intensity of low-frequency noise, a research program was developed to determine the potential of high-intensity, low-frequency noise to be a hazard to hearing. The data presented are from three experiments, two with animals and one with humans. An overview and summary of these data are presented.

METHODS AND PROCEDURES

Subjects

Experiment I

The subjects were eight, male binaural chinchillas which were randomly assigned to two groups of four subjects each. Chinchillas were selected as the animal model because their hearing is similar to man's and they are easily trained for behavioral audiometry (7).

Experiment II

Sixteen male, binaural chinchillas served as subjects. They were randomly assigned to four groups of four subjects each.

Experiment III

Five male, young adults served as subjects. Three subjects were tested under one procedure and two subjects were tested with a slightly different procedure.

Procedures

Experiment I

The procedure and apparatus have been discussed in detail elsewhere (2). Briefly, the chinchillas were initially trained

to respond to pure-tone signals. They were trained to move from one side of a shuttlebox to the other when a tone was presented to avoid a mild electric shock. Once trained with clearly audible tones (60-75 dB SPL), hearing thresholds at a number of frequencies were determined by systematically reducing the intensity level of the tones to the point where the subjects failed to emit a response. The level at which the subjects no longer responded was taken as the absolute threshold of hearing for each frequency.

After the baseline hearing thresholds were determined, the subjects were exposed to octave bands of noise in a sound room especially treated to produce a diffuse uniform sound field. The groups exposed to low-frequency noise were exposed to an octave band of noise with a center frequency of 63 Hz and the groups exposed to high-frequency noise were exposed to an octave band of noise with a center frequency of 1000 Hz. These noise bands were selected because they provide an example of two bands of noise that have a 26 dB difference in octave-band level while being equal with regard to A-weighted level. The intensity level of an octave band at 63 Hz is reduced by 26 dB in the conversion from octave-band level to A-weighted level, while the intensity level of an octave band at 1000 Hz is unchanged in the conversion (1). Also, 63 Hz was selected because it is a very high-intensity component of the noise generated by the IFV or CFV (9). The distribution of acoustic energy with frequency of the two noise bands used in the experiments are shown in Figure 1.

Each group of four subjects was exposed on separate occasions to their respective noise band at three intensity levels. The low-frequency group was exposed at levels of 100 dB SPL (74 dBA), 110 dB SPL (84 dBA), and 120 dB SPL (94 dBA). The high-frequency group was exposed at levels of 75 dB SPL (75 dBA), 85 dB SPL (85 dBA), and 95 dB SPL (95 dBA). Adequate time was allowed between exposures for hearing to completely recover and stabilize. The duration of each exposure was three days. Following exposure, the subjects' hearing was monitored until it completely recovered or for 30 days in those cases of permanent hearing loss.

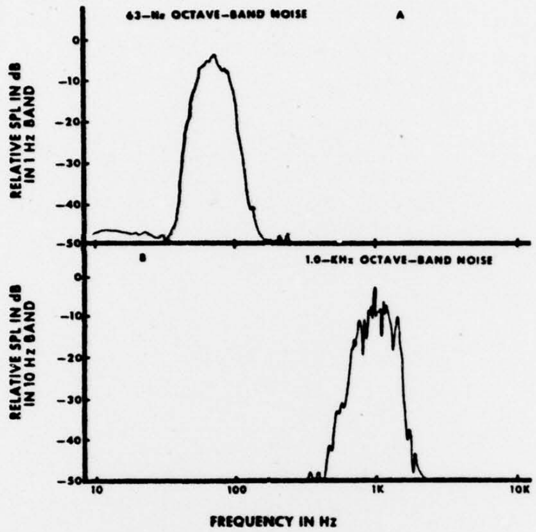

Figure 1. Power spectrum characteristics of the octave bands of noise used for exposure as measured in the sound field. Panel A depicts the octave band with a center frequency of 63 Hz and Panel B depicts the octave band with a center frequency of 1000 Hz.

Experiment II

The training, testing, and exposure conditions were as described above with the following exceptions: (1) of the four groups, two were exposed to the low-frequency noise and two were exposed to the high-frequency noise; (2) each group was exposed only once at a particular intensity level. One low-frequency group was exposed to 110 dB SPL (84 dBA) and the other was exposed to 120 dB SPL (94 dBA). One of the high-frequency groups was exposed to 85 dB SPL (85 dBA), and the other was exposed to 95 dB SPL (95 dBA); (3) the duration of the exposures was nine days.

Experiment III

The baseline hearing thresholds of the five human subjects were determined using the conventional audiometric procedure of tracking. They were then exposed individually to the same noise bands in the same sound field as the chinchillas. The subjects were exposed to the low-frequency noise at levels of 110 dB SPL (84 dBA) and 120 dB SPL (94 dBA), and to the high-frequency noise at levels of 85 dB

SPL (85 dBA) and 95 dB SPL (95 dBA). The duration of the exposures was four hours. The procedural difference between the two groups of subjects primarily involved the use of a different sequence of testing the frequencies during recovery. The hearing thresholds of all subjects were monitored until there was a complete recovery to baseline levels.

RESULTS

<u>Experiment I</u>

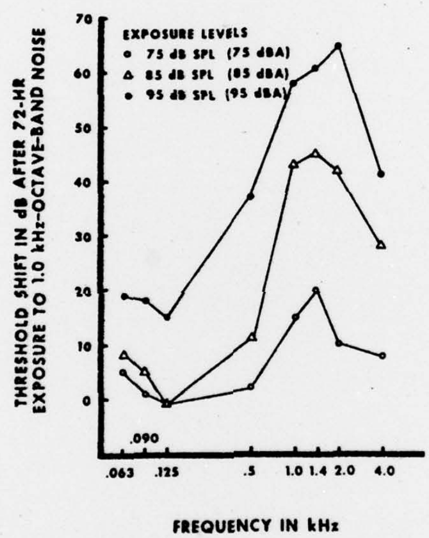

Figure 2. Threshold shifts between .063 and 4.0 kHz after a three-day exposure to octave band noise with a center frequency of 1.0 kHz at three exposure levels.

The threshold shifts for the 1000-Hz octave-band exposures are depicted in Figure 2. These data reflect the traditional pattern of threshold shift found with octave bands of noise with center frequencies of 500 Hz and above (4, 5, 6, 8). For example, as the level of the exposure band was increased systematically, an orderly increase in the amount of threshold shift occurred. For every 10 dB increase in exposure level, a concomitant increase in threshold shift of about 20 dB occurred at the frequencies maximally affected. In addition, the frequency region of greatest sensitivity to the 1000-Hz octave

band of noise occurred one-half to one octave above the center frequency of the exposure band, i.e., 1400 and 2000 Hz. This, too, is a classic finding for high-frequency octave bands of noise (4, 5, 6, 8). At the highest exposure level, the maximum threshold shifts were 61 dB at 1.4 kHz and 65 dB at 2.0 kHz.

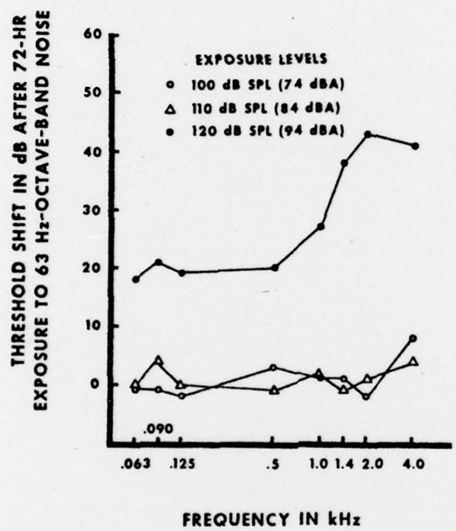

Figure 3. Threshold shifts between .063 and 4.0 kHz after a three-day exposure to octave-band noise with a center frequency of 63 Hz at three exposure levels.

The pattern of threshold shift for the low-frequency band of noise is quite different, however. This is shown in Figure 3. The two lowest exposure levels produced very little, if any, threshold shift. However, the highest level exposure, 120 dB SPL (94 dBA), produced dramatically different results. There was an abrupt appearance of a moderate to substantial threshold shift across the frequency range tested. This was a departure from the traditional results with high-frequency bands of noise. More interesting, however, was the frequency region in which the maximum shift occurred. Rather than occurring one-half to one octave (90-125 Hz) above the center frequency of the exposure band (63 Hz), it occurred five octaves above the center frequency at 2000 Hz. There was a slight elevation at the half-octave frequency of 90 Hz, but this was insignificant by comparison to the shift found at 2000 Hz. The amount of threshold shift found at 1.4 kHz was 39 dB and at 2.0 kHz was 43 dB.

The highest level exposure for the low-frequency noise, 120 dB SPL (94 dBA), produced permanent hearing losses in the subjects, and the highest level exposure for the high-frequency noise, 95 dB

TABLE I. Permanent threshold shifts in dB following three days of exposure to octave-band noise centered at 63 Hz at 120 dB SPL (94 dBA) and to octave-band noise centered at 1000 Hz at 95 dB SPL (95 dBA).

Frequency in kHZ	1.4	2.0
63 Hz Exposure Band	11	16
1000 Hz Exposure Band	6	9

SPL (95 dBA), also produced permanent hearing losses. These are given in Table I for 1.4 and 2.0 kHz. All other frequencies completely recovered. Not only did the exposure to the 63-Hz octave band produce a high-frequency hearing loss, a finding not previously known, but also, the low-frequency noise produced nearly twice as much permanent loss as the high-frequency noise. This has particularly important implications for damage-risk criteria since both of the exposure bands were within 1 dBA of each other in level and consequently should be considered equally hazardous. Another interesting result was that the threshold shift from the low-frequency exposures recovered considerably less than the shift from the high-frequency exposures.

Experiment II

The threshold shifts of subjects exposed to the two levels

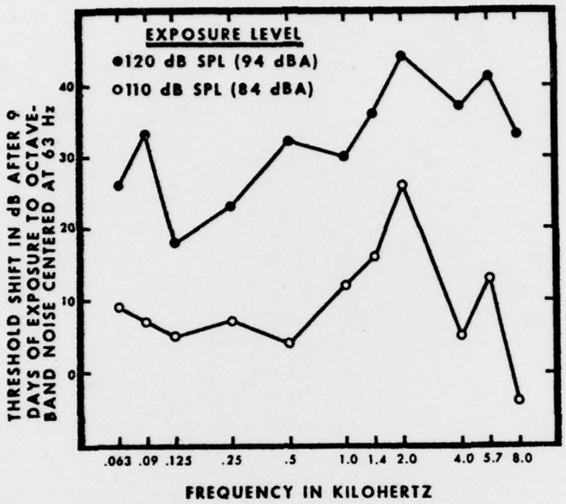

Figure 4. Threshold shifts between .063 and 8.0 kHz after a nine-day exposure to octave-band noise with a center frequency of 63 Hz at two exposure levels.

of high-frequency noise were virtually the same as those found for the three day exposure. Consequently these data are not presented. Figure 4 shows the threshold shifts for the subjects exposed to the low-frequency noise. Unlike the previous experiment, those subjects exposed to the level of 110 dB SPL (84 dBA) showed a small to moderate threshold shift with the maximum shift at 2.0 kHz. This difference between the studies is likely a function of the longer exposure duration. The high-level exposure group, 120 dB SPL (94 dBA), showed considerable shift at all frequencies tested. Again, this is probably due to the longer exposure. This exposure produced the largest shifts in the high frequencies. Threshold shifts in excess of 30 dB and 40 dB occurred at all frequencies between 500 and 8000 Hz as well as at the half-octave frequency of 90 Hz. The maximum shift of 44 dB again occurred at 2.0 kHz. Both groups clearly incurred a high-frequency shift to the low-frequency noise.

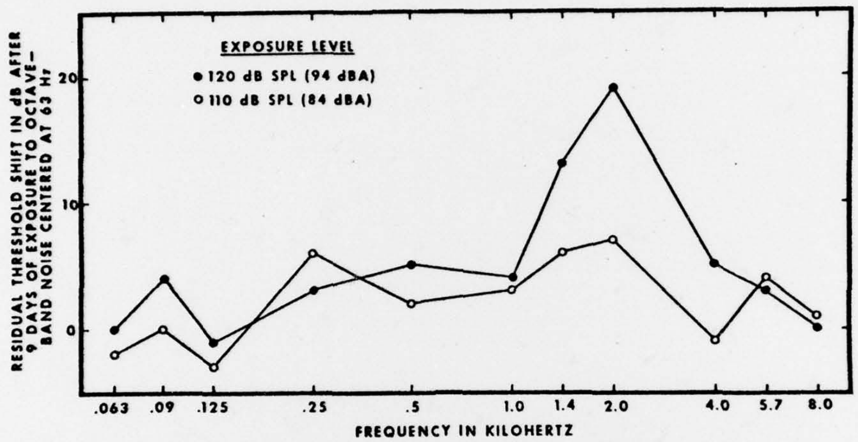

Figure 5. Permanent threshold shifts between .063 and 8.0 kHz obtained 30 days after the termination of a nine-day exposure to octave-band noise with a center frequency of 63 Hz at two exposure levels.

The permanent hearing losses which resulted from the low-frequency exposures are shown in Figure 5. Small permanent losses occurred at 250, 1400, 2000, and 5700 Hz from the 110 dB SPL (84 dBA) exposure, reflecting high-frequency hearing loss to the low-frequency noise. The 120 dB SPL (94 dBA) exposure resulted in permanent losses of 13 dB at 1400 Hz and 19 dB at 2000 Hz which are in excellent agreement with those found for the three-day exposure.

The comparison of permanent hearing losses incurred by the high-level exposure to the low- and high-frequency noise bands is given in Table II. The differences between the two losses are relatively small. Unlike the previous experiment the permanent losses were more in line with the predictions of the damage-risk criteria. That is, the high-frequency noise produced slightly more hearing loss than the low-frequency noise which is compatible with the high-frequency band being 1 dBA more intense. Again, the shifts for the high-frequency noise recovered substantially more than did the shifts for the low-frequency noise.

Table II. Permanent threshold shifts following nine days of exposure to octave-band noise centered at 63 Hz at 120 dB SPL (94 dBA) and to octave-band noise centered at 1000 Hz at 95 dB SPL (95 dBA).

Frequency in kHz	1.4	2.0
63 Hz Exposure Band	13	19
1000 Hz Exposure Band	17	28

Experiment III

The temporary threshold shifts found with the human subjects exposed to low-frequency noise are shown in Figure 6. All subjects recovered to their baseline levels. Although the shape of the threshold shift curves are not identical to those of the chinchillas, a good deal of shift occurred at 1.4 and 2.0 kHz, indicating that low-frequency noise also affects the high-frequency hearing of humans. Some of the difference between the two groups of humans may result from using a different order of testing the various frequencies and an interaction of this with the rapid recovery of hearing that occurs to the short duration exposure. These results indicate that the high-frequency hearing losses found with chinchillas are not unique to the chinchilla and that the human ear tends to respond in a similar way.

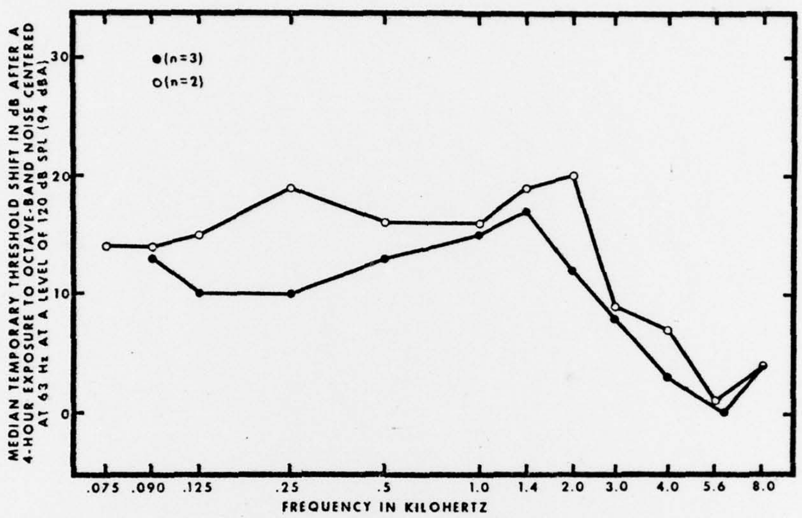

Figure 6. Temporary threshold shifts found in two groups of human subjects between .075 and 8.0 kHz after a four-hour exposure to octave-band noise with a center frequency of 63 Hz at 120 dB SPL (94 dBA).

DISCUSSION

The low-frequency exposures with chinchillas have consistently had their maximum effect on high-frequency hearing. The temporary threshold shifts in humans indicate that the human ear responds to low-frequency noise in a like manner. Also, the high-frequency threshold shifts produced in the animals by low-frequency noise showed considerably less recovery than high-frequency shifts produced by high-frequency noise. This indicates that low-frequency noise may have a more "potent" effect on hearing than high-frequency noise. These results together indicate that high-intensity, low-frequency noise may be a hazard to hearing which was previously unrecognized. Because A-weighting de-emphasizes the effects of low-frequency noise, the current damage-risk criteria may be inadequate and allow exposure of personnel to hazardous acoustic environments. Although the evidence is not clear-cut at this time, the findings of these experiments emphasize the need for much more research and raise serious questions concerning the adequacy of the current damage-risk criteria with regard to low-frequency noise.

Although the implications of the results for the damage-risk criteria are equivocal at this time, the new finding of a high-frequency hearing loss from low-frequency noise is significant. All previous research on noise-induced hearing loss has found that the maximum effect on hearing of a band of noise occurs one-half to one octave above the frequency of the noise band. A persistent problem in attempting to account for noise-induced hearing loss has been the consistent finding of primarily high-frequency hearing losses regardless of the noise source. These previous findings account for the emphasis currently placed on high-frequency noise as the primary hazard to hearing. It is now known, from the results presented in this paper, that the effect of low-frequency noise is far removed in frequency from the frequency of the exposure band. The present findings show, for the first time, that high frequency hearing losses can be induced by low-frequency noise. This may account for the phenomenon of high-frequency hearing loss in individuals exposed to low-frequency noise. These results also clarify the enigma concerning the consistent failure to find permanent low-frequency hearing losses in individuals exposed to low-frequency noise.

CONCLUSIONS

The following conclusions are made: (1) low-frequency noise produces permanent high-frequency hearing loss in chinchillas; (2) the human ear shows a similar pattern of temporary threshold shift; (3) the current damage-risk criteria may be inadequate and may require revision to deal with high-intensity, low-frequency noise.

ACKNOWLEDGEMENTS

In conducting the research in Experiments I and II, the investigators adhered to the "Guide for the Care and Use of Laboratory Animals," as promulgated by the Committee on Revision of the Guide for Laboratory Animal Facilities and Care of the Institute of Laboratory Animal Resources, National Research Council.

In conducting the research in Experiment III, the human subjects participated in this study after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Reg 70-25 on USE of VOLUNTEERS in RESEARCH.

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